N72-29979

NASA TECHNICAL MEMORANDUM

NASA TM X-2614

NASA TM X-2614

GENERAL METHODOLOGY: COSTING, BUDGETING, AND TECHNIQUES FOR BENEFIT-COST AND COST-EFFECTIVENESS ANALYSIS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1972

1 Report No	2 Government Accession No	3 Recipient's Catalog No
NASA TM X-2614		
4 Title and Subtitle GENERAL METHODOLOGY COSTING, BUDGETING, AND TECHNIQUES FOR BENEFIT-COST AND COST-EFFECTIVENESS ANALYSIS		5 Report Date August 1972
		6 Performing Organization Code
7 Author(s) D Michael Stretchberry and Gerald F Hein		8 Performing Organization Report No E-6906
		10 Work Unit No 682-10
9 Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11 Contract or Grant No
		13 Type of Report and Period Covered Technical Memorandum
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D C 20546		14 Sponsoring Agency Code

15 Supplementary Notes

16 Abstract

In the first part of the report the general concepts of costing, budgeting, and benefit-cost ratio and cost-effectiveness analysis are discussed The three common methods of costing are presented Budgeting distributions are discussed. The use of discounting procedures is outlined The benefit-cost ratio and cost-effectiveness analysis is defined and their current application to NASA planning is pointed out. The second part discusses specific practices and techniques Actual costing and budgeting procedures are outlined. The recommended method of calculating benefit-cost ratios is described A standardized method of cost-effectiveness analysis is discussed. Long-range planning is discussed

17 Key Words (Suggested by Author(s))	18 Distribution Statement
Cost estimating, Capital budgeting, Benefit-cost analysis, Benefit-cost ratio, Cost-effectiveness analysis, Long-range planning, Engineering economy	Unclassified - unlimited

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price*
Unclassified	Unclassified	19	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

Benefit-cost ratio and cost-effectiveness analysis are two powerful planning tools that NASA should utilize more. Better utilization of NASA's current funding as well as better opportunities to gain increased future funding could result. However, the use of benefit-cost analysis depends on whether the benefits can be specified and quantified. Thus, methods of determining the benefits of NASA programs should be developed. This report summarizes the general concepts and specific practices of costing and budgeting which are necessary for benefit-cost analyses. Then, benefit-cost ratio and cost-effectiveness analyses are discussed.

Each part of the costing statement is discussed, and methods are given to do the necessary costing and budgeting tabulations. The method of calculating the benefit-cost ratio of a program is given. A standardized approach of doing cost-effectiveness analysis is described. The use of the incremental benefit-cost ratio is illustrated. Some common problems of cost-effectiveness analyses are discussed. Long-range planning is discussed and an example of simulation is outlined.

INTRODUCTION

This report summarizes the general methodology of costing and budgeting of proposed programs. It also summarizes the use of benefit-cost ratios and cost-effectiveness analysis to evaluate programs or alternatives to do a program. The general concepts that influence costing, budgeting, and benefit-cost analysis are discussed first. Long-range planning concepts are also presented. Then specific practices and techniques are discussed and illustrated for most of the general concepts.

Long-range planning is important for government agencies as well as for businesses. Benefit-cost analysis (which includes both benefit-cost ratio and cost-effectiveness

analysis) is a powerful planning tool. NASA's budget has been decreasing steadily for several years. At its peak, the goals of NASA were well defined and funds were easily available. Now, however, opinions on what NASA should do in the future differ considerably. Any program that is chosen must be done as economically as possible. Benefit-cost analysis can be used to select the best program and then can be used to choose the most economical alternative to do the program. However, the use of benefit-cost analysis depends on whether the benefits can be specified and quantified. This is difficult. General comments are made about this planning tool and the problems which arise when trying to use the tool.

General concepts will be discussed first. The three methods of costing - the engineering method, the cost estimating relationship, and the proportional method - will be defined. The various budget distributions characteristic of the different types of costs will be described. The potential importance of benefit-cost ratios and cost-effectiveness analysis for long-range planning is discussed. Capital recovery costs and present worth of costs and benefits are needed for benefit-cost analysis. These in turn require the use of a discount rate. Some general comments on long-range planning are also included.

Specific procedures and techniques are then described. The costing statement consists of tables of investment, annual operations, capital recovery, and the budget distribution, and also text to discuss each. Each part is discussed and methods are given to do any necessary tabulations. The method of calculating the benefit-cost ratio of a program is given. The internal rate of return is also used to rank different programs. A standardized approach of doing cost-effectiveness analyses is described. The use of the incremental benefit-cost ratio is illustrated. Some examples of effectiveness criteria are given. A few common problems of cost-effectiveness analyses are also discussed. A simulation example is given.

GENERAL CONCEPTS

The first section of this report discusses the general concepts and principles that influence costing, budgeting, and benefit-cost analysis of a proposed program. These concepts are principles that have originated from economic theory, accounting, management finance, operations research, and others.

Costing and Budgeting

Costing methods (refs. 1 and 2). - The three techniques used for program costing are the following:

(1) Engineering method (detailed cost estimate) - Each part of the program is costed individually and all costs are added to obtain total program cost.

(2) Proportional method - The known costs of a program are used as the basis of the cost estimate for the future program. The known costs are scaled up or down to the required size for the future program.

(3) Cost Estimating Relationship (CER) - A mathematical relation is determined between historical program costs and various characteristics of previous programs. This relation is used to predict future program costs on the basis of known design parameters.

All three methods are normally used in varying degrees for determining cost estimates. Estimates made with the engineering method tend to be lower than the true cost. It should be noted that the proportional method of estimation is an extrapolation from a single-point cost estimating relationship. Thus the proportional method of estimation is not valid mathematically. The use of a CER is generally the most satisfactory, but it also has limitations. First the relationships is valid only within the limits of the data used to establish the CER. Moreover, any extrapolation beyond the bounds of the original data of a CER has decreased accuracy as the distance from the bounds increases. Cost estimates should be made using other methods if the bounds of the CER are exceeded significantly. If other methods are not available, the one obtained by extrapolation from a CER may be used judiciously since cost functions seldom have extreme discontinuities. However, the associated statistics such as confidence intervals are meaningless. If such an extrapolation from a CER is used, it should be specified as such, and the bounds of the cost estimate should be approximated as best as possible.

Budgeting. - The costs to start and sustain a program are of three types (ref. 2): research and development (R&D), investment, and annual operations. These costs have different funding distributions over time. The R&D cost distribution usually resembles a normal curve (refs. 1 and 2). If the program incorporates technical advances or modifications in the future, then the R&D investment distribution will be repeated. The distribution for investment of manufactured hardware can also be approximately normal if hardware production is in small lots. Large volumes of hardware production require an approximately linear rise to a constant level (ref. 3). Hardware investment will be periodically repeated due to the limited lifetime of any piece of hardware. Annual operations costs will start soon after hardware investment is started and will usually rise to their maximum and approximately constant level at about the time that initial hardware investment is completed. The annual operations will not change from year to year unless the program is changed.

The actual amount spent each year is the total of the three types of costs that are actually spent each year. Thus the budget for any year in the future is simply the sum of the three costs for that year. All the dollar figures should be initially expressed in current dollars for all costing and budgeting. However, once the budgeted amounts are known for the current year and all years in the future, then the effects of inflation can be

Benefit-cost ratio (ref. 4). - Both private and public decision makers must choose between different types of programs which are competing for limited resources. The benefit-cost ratios of programs are used to rank the programs to decide which will be done first. The benefit-cost ratio is the sum of all the benefits over the life of the program divided by the sum of all the costs. Both benefits and costs of all years are expressed in present value. The program with highest ratio should be chosen first because it has the greatest benefit per unit cost. However, no program should be done if the ratio is less than one. In addition to consideration of the benefit-cost ratio, additional information such as the magnitudes of the costs and benefits should be examined.

Cost-effectiveness analysis. - When considering alternatives for the same program, a cost-effectiveness analysis is done. This analysis examines the alternatives and compares both costs and benefits (effectiveness) to choose the "best" alternative. However, a direct comparison of benefit-cost ratios of the alternatives is incorrect. Incremental benefit-cost ratios must be calculated and used for comparing the alternatives (refs. 1, 5, and 6). Incremental costs or benefits are the increases in costs or benefits from one alternative to the next and not the total costs or benefits of an alternative. The more obvious cost-effectiveness analyses are those where either the costs for all the alternatives are the same and the effectiveness or benefits are different or where the benefits are the same but the costs differ. Note that effectiveness criteria do not have to be dollar (economic) benefits necessarily. They can be performance criteria.

A program is justified by use of the benefit-cost ratio. In this case there must be reason to believe that the benefits (usually dollars) are greater than the costs (usually dollars). For example, a weather satellite program is chosen because the benefit-cost ratio is greater than one (and greater than the ratios of other potential programs). Then a cost-effectiveness analysis is done to choose the best way of doing the program. Criteria now would normally be performance related. Terms that are often used to imply the concept of effectiveness are utility, productivity, worth, merit, and benefit (ref. 7). The term benefit is favored by the Office of Management and Budget while the term worth is generally favored by engineers.

The value of benefit-cost analysis to NASA. - Benefit-cost ratios and cost-effectiveness analysis are two important tools that should be used more by NASA. The use of these tools will help NASA to make decisions in order to best utilize its budget. The benefit-cost ratios can also be used to demonstrate the worth of NASA programs. But none of this can be done unless the benefits are specified and quantified. The costs of programs can usually be estimated but the benefits are difficult to identify. Standard methods are required to identify the benefits resulting from NASA programs. Work should be done to develop these standard methods. Both direct and indirect benefits must

be specified as well as short-term and long-term benefits. The benefits must then be converted to quantitative values if at all possible. With increased competition for scarce funds, the areas of benefit analysis and program selection are emerging as two extremely important planning tools.

Units of measure of costs and benefits. - The costs and benefits of a program may be expressed in several different units. (See ref. 7 for a listing.) Costs are nearly always expressed in dollars except in the case of human life (although values have been estimated for the economic worth of an average lifetime). Benefits may be expressed in dollars, dollar analogues, human lives, time saved, and in terms of goods or services received. Other units of cost and/or benefit may be used but the units tend to be somewhat intangible and extremely difficult to measure. For example, national morale may suffer (negative benefit) or improve (positive benefit) as a result of a program, or our national image abroad may be affected (cost or benefit). Besides being difficult to measure, the value of the morale unit is quite subjective and the measure itself may be short-lived. When feasible, program costs and benefits should be expressed in dollars. When dissimilar units arise in a benefit-cost analysis and there is no acceptable method of transformation to similar units, the information should be given without comparison.

The cost and benefits to be included (ref. 8). - The terms "cost" and "benefit" are used loosely by some in discussing benefit-cost analysis. Only some "costs" and "benefits" should be included in the benefit-cost analysis. Of course, those direct costs of the program and the direct benefits resulting from the program should be included. These costs and benefits accrue to the agency that proposes the program. Some costs and benefits accrue to persons other than the agency that proposes the program. These are called externalities (or spillovers) and must also be included. For example, a Federal program may be estimated to cost a certain amount and this amount is provided for in the Federal budget. But if private spending is also required to implement the program, then this must be considered a cost. The private spending is a cost regardless if it is voluntary or mandatory.

Secondary costs or benefits should not be included. For example consider a crop monitoring satellite. The benefit is the increased crop produced because of the better monitoring and planning possible due to the satellite. The costs are the satellite cost plus the cost of the extra inputs to grow the crop. However, no other costs or benefits are imputed for the processes done to the extra crop before it reaches the consumer. These are secondary costs and benefits and are a component of the benefit calculated before.

Other ways of comparing programs. - There are two other widely used ways of comparing programs (ref. 5). Both are related to the benefit-cost ratio tool. The first is called the equivalent annual cost and the other is the rate of return (also known as the internal rate of return). The equivalent annual cost is simply the sum of the annual operations cost and the annual share of the investment cost. The rate of return is an interest

rate that indicates the investment yield of the program. All three tools give identical results. It is a matter of convenience or tradition whichever is used. All three utilize the concept of the discount rate which will now be discussed.

Discount rates (refs. 5 and 4). - Money has a time value which, for example, makes \$1.00 received today worth more than \$1.00 received next year. This is so because the \$1.00 received today could be invested to yield more than \$1.00 by next year. The time value of money has implications for benefit-cost analysis.

The equivalent annual cost of a program (which is more precisely known as the equivalent uniform annual cost (ref. 5)) must include a capital recovery cost. The capital recovery cost accounts for several factors. First, it accounts for a specific year's use of the total investment cost. Investment costs are not explicitly a part of the equivalent annual cost of a program. The capital recovery cost also takes into account the uncertainty of a program. The uncertainty can be due to the difficulty of forecasting costs and benefits accurately or the threat of obsolescence. Finally, for private industry, a profit margin must be included. When the discount rate (an interest rate) and the lifetime of the investment have been determined, the capital recovery cost can then be calculated. The discount rate is at least as large as the interest rate on money borrowed to finance the program. This rate is adjusted upward to reflect the uncertainty of the program and the profit margin required by private industry. Currently the Office of Management and Budget recommends that all federal government programs use a discount rate of 10 percent and then check for sensitivity between about 8 to 12 percent. For private industry the discount rate should be about 15 percent for low risk programs and as much as 20 percent for high risk programs.

Another use of the discount rate is the calculation of the present worth of all future costs and benefits. This is required for calculating benefit-cost ratios and for performing cost-effectiveness analyses. In this manner, meaningful comparisons can be made for various program alternatives.

Long-Range Planning

Long-range planning is concerned with a period of more than one year. Normally this type of planning is done for a five-year period. Short-range planning is concerned primarily with periods of less than one year and with budgeting and accounting activities. The activities of long-range planning according to one author are (ref. 9):

(1) Forecasting

(2) Budgeting and accounting

(3) Setting goals and designing action programs

Forecasting. - The purpose of the forecast is to provide an estimation or description of the future so that alternatives to various contingencies may be developed. The

techniques used in forecasting and the required statistics have been greatly improved in recent years, and information required to make realistic forecasts is no longer so expensive as to render the costs prohibitive. Despite advances, however, the quality of long-range forecasting falls short of what is possible because many forecasts are simply extrapolations of trend. In other words, the future is assumed to be a continuation of the present. Thus the value of forecasting is reduced because the range of contingencies considered is extremely narrow.

Budgeting and accounting. - The primary function of budgeting is the translation of plans into financial terms. Quite often budgeting is equated to planning; hence, many controllers and budgetary directors are given the responsibility for planning which may account for some of the lack of emphasis on forecasting activities. For short-range planning which is primarily the allocation of resources within existing policy, this situation is not critical. However, for long-term policy determination that may be designed to alter the course of the organization, planning requirements usually exceed the limits of budgeting and accounting. In addition to resource allocation, the budgeting and accounting functions include the exposition of less obvious implications of financial plans and the consultation to management required to achieve financial goals in the administration of programs.

Setting goals and designing action programs. - The requirements for this, the most important function, are:

(1) To analyze projections of the future in order to realistically set desired goals
(2) To analyze specific obstacles preventing the fulfillment of goals
(3) To design a program of action, not subjective affirmations, designed to overcome the obstacles

The fulfillment of these three requirements ensures the avoidance of crisis management or decisions designed to "fill the gaps." The performance of these functions also allows the luxury of avoiding subjective estimates since the genuine and specific problems have been well-defined. If the gaps are not identified, it is impossible to clarify the problems and needs, and so programs will not be meaningfully designed.

SPECIFIC PRACTICES

Applications of general concepts presented thus far will now be discussed. Specific procedures and techniques will be given and examples will be used for illustration when possible.

Program Costing

The program costing statement should be utilized, which should include cost tables and explanatory text. There should be tables of R&D investment, hardware investment, annual operations, capital recovery, and the budget distribution. The explanatory text should describe and explain the tables. Topics should include "Costing Limitations and Problems," "Investment," "Annual Operations," and "Budget."

The investment table should have separate listings for R&D and hardware investment, and have a grand total. Investment items are land, buildings, equipment, and one-time services. An amount for "Development and Systems Engineering" equal to 10 percent (nominal) of investment should be allowed for those parts of the hardware investment for which R&D costs have not explicitly been determined.

The annual operations table accounts for items such as maintenance, staffing, and utilities. Maintenance each year may be assumed to be 10 percent of the hardware investment. Staffing costs may be estimated by doubling salaries for professionals and using a factor of 1.5 for nonprofessionals to account for overhead, vacations, and benefits. For cases where continuous operation is required, five shifts per week will allow for unavoidable absences.

A table of annual capital recovery costs is also important. A capital recovery cost must be calculated for every investment item. To calculate capital recovery, both the discount rate and the estimated life of the item must be known. Interest tables (ref. 5) tabulate the "capital recovery factors" necessary to calculate the capital recovery cost. For example, assume a piece of electronic gear is estimated to have a 10-year life and that the discount rate is 5 percent. From the interest tables the capital recovery factor for 10 years at 5 percent is 0.12950. The capital recovery cost is the investment cost of the piece of electronic gear times 0.12950. Thus more than one-tenth of the investment cost must be assigned to each year even though the life of the gear is 10 years. This is due to the time value of money. A capital recovery cost is also calculated for "Development and Systems Engineering."

Sensitivity calculations for the discount rate should be tabulated in the capital recovery table. These calculations involve refiguring the capital recovery costs at the minimum and maximum discount rates. For example, for government programs the discount rate recommended by OMB is 10 percent. The capital recovery costs are calculated using 10 percent and these cost figures are then used as needed in the benefit-cost ratio and cost-effectiveness analyses. Capital recovery costs should then also be calculated using a discount rate of 8 and 12 percent. The purpose of doing this is to determine if the equivalent annual cost or the cost-effectiveness analysis changes significantly with a change in the discount rate.

Budgeting

A very important part of the program costing statement is the budget distribution table. It is always necessary to tabulate the budget (annual spending) or the equivalent annual cost over the life of the program or a group of programs. This is direct information for the federal budgetary planners and also yields part of the information needed for the benefit-cost analysis. All the dollar figures in the budgeting should be expressed in current dollars (taking no account of inflation). Then all the required analyses (such as benefit-cost ratio calculations or jobs created) are done. If necessary, the dollar amounts can be recalculated to include the effects of inflation.

The budget distribution table should be similar to that shown in figure 1. Note that the actual annual spending on a program is the total of investment plus annual operations.

Fiscal year	1973	1974	1975	1976	1977	etc
Investment, total Research and development Hardware						
Annual operations						
Capital recovery						
Budget (investment and annual operations)						
Equivalent annual cost (annual operations and capital recovery)						

Figure 1 - Suggested budget distribution table

However, this is not the test figure to use doing benefit-cost analysis. These figures must be converted to present value costs. Alternatively, the equivalent annual cost (which is annual operations plus capital recovery) can be used.

The investment costs (such as R&D and manufactured hardware costs) are assigned to each year of the life of the investment by use of the capital recovery cost. In this way the benefits due to the program are better matched to the costs incurred in carrying out the program. This matching of benefits and costs is a well established accounting principle.

Note that an estimate of the total jobs created or sustained each year by the budget spending can be made. First estimate the spending required to generate one job and then divide that into the total budget for the year. Different types of jobs can be accounted for since there are different types of investment (R&D, highly technical hardware, or mass produced hardware, for example) and various types of people required to staff and main-

tain the program. But note that only if there is a net addition to spending, total private and public, will jobs be created. Also, spending must be maintained each year to sustain the jobs.

Examples of the funding distributions to be used for all the items in the aforementioned budgeting table are shown in figure 2. The relative position of each distribution may be changed to fit a particular program. In the figure, 0 percent is the start of funding for the program. The full operations point is 100 percent. The R&D investment is assumed in this example to extend from 0 to 80 percent and is shaped normally. The hardware investment is assumed to be distributed normally also if only a few units are to

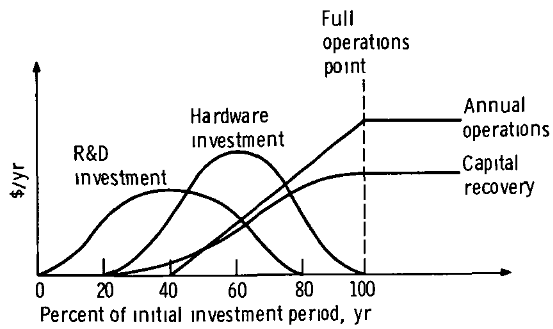

Figure 2 - Possible funding distributions for various types of costs

be purchased. (For example, a program using only two or three satellites would have its hardware investment distributed normally (ref. 10). If a program will use many units, the distribution will be trapezoidal shaped as will be discussed below). Annual operations are assumed to start at 40 percent and rise linearly to its full cost at 100 percent. Capital recovery costs are assumed to start the same time as hardware investment and rise to its full cost at 100 percent. The capital recovery distribution will be directly proportional to the cumulative hardware investment.

The trapezoidal shaped hardware investment distribution cited previously for the multi-unit case is shown in figure 3. It increases approximately linearly in 1 or 2 years to a maximum constant value. This level of investment is funded until 1 or 2 years before the end of the investment period. For the last 1 or 2 years investment decreases linearly to zero. The figure shows how the percentage of total investment for each year can be calculated. As an example, assume a hardware investment for 9 years with the investment linearly increasing for 2 years at the beginning and linearly decreasing for 2 years at the end of the investment period. This 9-year trapezoidal hardware investment distribution extends from the 20-percent point in figure 2 to the 100-percent point (full operations point). Note that there are 5 full investment years, 2 years where investment is

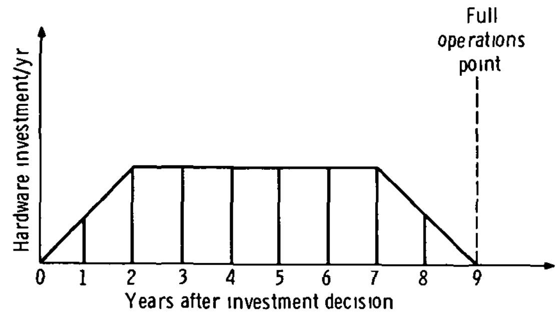

Figure 3 - Hardware investment distribution for case where many units are to be produced

three-fourths of full investment, and 2 years where investment is one-fourth of full investment. Adding all these yearly investments and equating to 100 percent (total hardware investment) gives the result that 1 year at full investment is 14.3 percent of the total investment. Thus, at the end of the first year, one-fourth of 14.3 percent (= 3.6 percent) is the percentage of the total investment actually required. During the second year, three-fourths of 14.3 percent (= 10.7 percent) of the total was invested. During the third year 14.3 percent of the total was invested. Investment during the rest of the years is found similarly. Other investment distributions involving a longer or shorter period are calculated in the same manner.

Benefit-Cost Ratio Analysis

Reference 4 requires all government program planning documents to include a benefit-cost ratio when possible. The circular also gives the method of calculation to be used. Reference 5 confirms this method and recommends it for private as well as public programs. The ratio is simple to calculate once the proper benefits and costs are estimated. However, estimating the benefits and costs will usually be difficult.

The costs and benefits must be estimated for all years of the program in order to calculate the benefit-cost ratio. The dollar values should be expressed in current dollars. The effects of inflation should be ignored. All future costs and benefits must then be multiplied by a discount factor to transform them to present value costs or present value benefits. Sum all the present value costs or benefits for all years. A benefit-cost ratio can now be calculated.

If the program is limited in years, all that need be done is to divide the summed present value benefits by the summed present value costs. For a program that is to proceed indefinitely, the calculation depends on the number of years summed. The benefit-cost ratio will change as the number of years summed is increased. However, the ratio

will approach a constant value assuming the estimated benefits are constant due to a program of constant equivalent annual costs.

Often the internal rate of return is used instead of the benefit-cost ratio to rank programs. The internal rate of return is that discount rate which equates the summed present value costs and the summed present value benefits. While it can be calculated by iterative methods, tables are normally used.

Sensitivity analysis of the discount rate should be done at this stage to determine how the benefit-cost ratio changes with changes in the discount rate.

Cost-Effectiveness Analysis

A standardized approach. - Chapter 7 of reference 7 gives a standardized approach to cost-effectiveness evaluations. The author states that there has been a lack of uniformity of evaluations. Therefore, he has tried to extract common elements from numerous evaluations and then standardize the basic cost-effectiveness analysis. The approach lists ten specific steps. However, the ten steps fit into four general areas: (1) the goals and requirements of the program are specified and defined, (2) alternates for doing the program are conceived, (3) evaluation criteria are established, and (4) the analysis is performed. In area (4), a fixed-cost or fixed-effectiveness approach is recommended. However, this is not strictly required. Incremental benefit-cost ratios can be used in the general case where the alternatives are not either fixed cost or fixed effectiveness.

An example from reference 5 illustrates the use of incremental benefit-cost ratios. For a flood control project nine alternatives were suggested. The following table lists the plans by number with their annual project benefits, annual project costs, and their benefit-cost ratio:

Plan	Annual project benefits	Annual project costs	Benefit-cost ratio
5	$750	$199	3 77
4	700	208	3 37
3	800	220	3 64
8	900	407	2 21
7	1020	419	2 43
9	960	428	2 24
10	1150	627	1 83
2	1300	903	1 44
6	1350	1102	1 23

The tendency might be to pick plan 5 because the benefit-cost ratio is the largest. This would be incorrect. Total cost, including project costs and costs of flood damages, will be minimized if the plan is selected that yields the maximum of excess benefits over excess costs. In the following table, pairs of alternatives are compared and incremental benefit-cost ratios tabulated:

Plans compared	Increment of annual benefits	Increment of annual costs	Incremental benefit-cost ratio
4 over 5	$-50	9	Negative
3 over 5	50	21	2 38
8 over 3	100	187	53
7 over 3	220	199	1 11
9 over 7	-60	9	Negative
10 over 7	130	208	62
2 over 7	280	484	58
6 over 7	330	683	48

Note that, in calculating the incremental ratios, the pair should be picked such that the first alternative to be compared over the second alternative has the higher costs. This ensures that the incremental cost denominator will always be positive. If the calculated ratio is negative or less than one, the first alternative is not favored over the second alternative. If the ratio is greater than one, the first alternative is favored over the second alternative. In the previous table, plan 4 is not favored over plan 5 because the ratio is negative. Thus plan 4 is dropped from consideration because at least one of the other plans is better. Plan 3 is favored over plan 5 and thus plan 5 is eliminated. Plan 8 is not favored over plan 3 and plan 8 is eliminated. But plan 7 is favored over plan 3. Finally, plans 9, 10, 2, and 6 are not favored over plan 7. Thus plan 7 when compared to every other alternative is more favorable and is the best alternative.

Evaluation criteria. - Reference 7 lists evaluation criteria in chapter 7 and appendix B. These criteria are not standard criteria and the lists are not necessarily complete but are intended as examples and checklists. Most problems do not stem from cost criteria but from effectiveness criteria. Effectiveness criteria, unless very specific, are often not quantifiable. Examples of criteria that are hard to quantify are performance, safety, economy, prestige, probability of success, information received, and capability. Typical quantifiable criteria are range, speed, dollars per pound, power, and expected profit.

The selection of criteria depends on the judgement and the experience of the analyst.

Too few criteria or the wrong criteria can be selected and the analysis will not be valid. Too many criteria (10 or more according to ref. 7) will tend to paralyze the decision process.

Common problems to avoid. - The following are some points to consider which will help to avoid common problems of cost-effectiveness evaluations:

(1) Benefit-cost ratio: The actual magnitude of the numerator and denominator of the ratio and the risk associated with each alternative should not be ignored.

(2) Quantification: It is sometimes impossible to quantify all cost-effectiveness criteria which are pertinent to the evaluation or decision.

(3) Interrelations: Some cost-effectiveness criteria may not be transformed by a relation to a common criterion such as dollars cost or dollars effectiveness.

(4) Use of a single cost-effectiveness criterion: One single criterion can seldom be used as the sole basis of an evaluation.

(5) Weighting: There is no generally acceptable method of developing weights to judge the relative importance of various criteria.

(6) Assumption-of-probabilities: Probabilities are often not known but rather are assumed and may lead to erroneous conclusions. Hence, one must use prudence and common sense in evaluating these probability estimates and the conclusions which result.

(7) Use of a fixed amortization period: The use of unrealistic life-times for systems may produce misleading results because of the sensitivity of annual and total costs and benefits to system life.

(8) Neglect of spillover effects: There will be horizontal and vertical externalities (spillovers) both good and bad that may need to be considered.

Two Projections

Since planning is concerned primarily with the formulation of alternatives, it is necessary for management to perceive changes. There must be an understanding of the following:

(1) Trends and shifts affecting the economy

(2) Technical developments

(3) Competition

(4) Consumer demands

(5) Changing nature of organizational operations

It is impossible to adequately treat all the techniques associated with the perception of change but examples will be given to demonstrate the necessity of recognizing change and the performance of the forecasting function. This information is from an unpublished 1965 monograph by Joseph DiMario entitled "Effective Strategic Planning."

Subjectivity in forecasting, goal setting, and the design of programs must be avoided. An example of what to avoid is now provided which deals with the 1964-1965 World's Fair. Attendance at the fair totaled 27 million people in 1964. Attendance in 1965 was projected to be 39.5 million or an increase of 39 percent. This projection was unrealistic for two reasons:

(1) Attendance in the second year of a fair historically drops at least 30 percent below that of the first year.

(2) The admission price was raised 25 percent in 1965.

Attendance during the first 2 months of 1965 ran 50 000 people per day below the 1964 level. The projection of 39.5 million people for 1965 may have been realistic if some plan had been initiated to ensure the meeting of the goal, but such was not the case.

There are many techniques available for use in forecasting. Each deserves more space than is available here. So this report is limited to a short example of the use of one technique, simulation. The example is from reference 11.

This example deals with determining future requirements for a facility which services one arrival at a time and queues those which arrive while another request is being serviced. Although simple, the example is typical of many situations encountered in service industries, repair shops, telephone lines to computers, and so on. For purposes of analyzing the problem, the following assumptions are made. Arrivals attempting to enter the queue will turn away and the value of the service will be lost if and only if there are no places available in the queue. Once entering the queue, the arrival will remain until serviced. Units will arrive for service according to a Poisson input process at the mean rate of 32 per minute. The time required for service has an exponential distribution where the mean service rate is 40 per minute. The net value (or profit) for each unit serviced is approximately \$1.00. The capitalization and expenses are approximately \$0.40 per minute for each place in the queue. The objective is to determine the number of places in the queue which maximizes expected net value.

Let V denote the expected net value, so that the objective is to maximize V. One expression for V is

$$V = (1.00)(32)(1 - P_{N+1}) - 0.40\ N$$

where N is the number of places in the queue, and P_{N+1} is the probability of having $N + 1$ units in the system so that all N places are occupied (arrivals will turn away). This formulation may be solved with queuing theory.

It is somewhat easier to solve the problem using simulation. The expression which was used for V is

$$V = 1.00\ S - 0.40\ N$$

where S is the number of units serviced per minute. By using simulation to estimate S for various values of N, the optimal value of N was estimated.

The first step was to run the simulation model for various values of N in order to obtain preliminary estimates of V. This run revealed that N = (5, 6, 7, 8) were the candidates for the optimal value of N, with N = (6, 7) as the prime candidates. This preliminary investigation was also used to determine reasonable starting conditions, to estimate the time required for the simulated system to essentially reach a steady-state condition, and to estimate the required sample sizes. The next step was to execute long simulation runs for each of these four values of N. Each of these runs was continued for 1500 simulated minutes after the system essentially reached a steady-state condition. The 1500 minutes were divided into 15 equal portions of 100 minutes each. The data recorded were the average net value for each of the portions. The same sequences of random numbers were used for each of the runs so that the sequences of inter-arrival times and service times would be the same on the respective runs. When comparing the performance for two values of N, the relevant information was the value of d_i, the difference in the average net value during portion i between the first and second values of N for i = 1, 2, ..., 15.

For example, consider N = 7 and N = 8. The estimates of V obtained from the corresponding simulation runs were \$28.045 and \$27.973, respectively, so that the difference was \$0.072. However, this does not prove that the true value of V is larger for N = 7 than for N = 8. It is necessary to take statistical error into account. By taking the difference for each of the 15 portions, the average difference,

$$\bar{d} = \frac{1}{n} \sum_{L=1}^{n} d_i = \$0.072$$

and the sample standard deviation of the difference

$$s = \sqrt{\frac{\sum_{L=1}^{n} (d_i - \bar{d})^2}{n - 1}} = \$0.58$$

were obtained, where the sample size was n = 15. The estimated standard deviation of the average difference is $s/\sqrt{n}$ = \$0.0408. Thus, the corresponding t statistic is

$$t = \frac{\bar{d}}{s/\sqrt{n}} = 1.76$$

where 1.76 also happens to be the 95 percent point of Student's t-distribution with $n - 1 = 14$ degrees of freedom. Therefore, the hypothesis that the mean difference is zero (i.e., V is the same for $N = 7$ and $N = 8$) is rejected in favor of the alternative hypothesis that the mean difference is positive (i.e., V for $N = 7$ is larger than V for $N = 8$) at the 5 percent level of statistical significance.

Proceeding in the same manner, it was found that V for $N = 6$ is larger than V for $N = 5$ at an acceptable level of statistical significance. This left only $N = 6$ and $N = 7$ to be compared to determine which value maximizes V. The simulation runs had yielded \$28.068 and \$28.045 as the estimates of V for $N = 6$ and $N = 7$, respectively. Taking the differences for the corresponding portions of the runs, it was found that the average difference was $\bar{d} = \$0.023$, and the sample standard deviation of the difference was $s = \$0.171$. Thus, the estimated standard deviation of the average difference was $\$0.171/\sqrt{15} = \$0.0442$. The t-statistic was $t = 0.023/0.0442 = 0.52$. Therefore, the hypothesis that $N = 6$ and $N = 7$ have the same value of V cannot be rejected at any reasonable level of statistical significance. The difference in the estimated values of V is not statistically significant. To distinguish between the true values of V would require much longer simulation runs (approximately 10 times as long). The conclusion is that six and seven places essentially tie for maximizing expected net value, so that the selection should be made on the basis of the intangibles involved.

CONCLUDING REMARKS

This report has summarized the general concepts and the specific practices involved in the costing, budgeting, and benefit-cost analysis of proposed programs. Each part of the costing statement was discussed and methods were given to do the necessary costing and budgeting tabulations. The methods of calculating the benefit-cost ratio of a program was given. A standardized approach of doing cost-effectiveness analysis was described. The use of the incremental benefit-cost ratio was illustrated. Some common problems of cost-effectiveness analyses were discussed. The three activities of long range planning (forecasting, budgeting and accounting, and setting goals and designing action programs) were also discussed.

It has been proposed that NASA make more extensive use of the benefit-cost ratio and cost-effectiveness analysis planning tools. To do this, methods of determining the

benefits of NASA programs must be developed. Better utilization of NASA's current funding as well as better opportunities to gain increased future funding could result.

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NASA-Langley, 1972 —— 34 E-6906

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